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RESEARCH ARTICLE

ASSESSMENT OF RADIATION RISK LEVELS ASSOCIATED WITH NATURAL (^{226}RA, ^{232}TH, AND ^{40}K) AND ARTIFICIAL (^{137}CS) RADIONUCLIDES PRESENT IN POWDERED MILK SOLD AND CONSUMED IN SENEGAL

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Abstract

The study conducted in Senegal sought to address the dearth of data on radionuclide concentrations in milk, particularly considering the upward trajectory of domestic consumption. Employing gamma-spectrometry, researchers investigated five milk brands, calculating the resulting ingestion dose. The concentrations of ^{232}Th, ^{226}Ra, ^{137}Cs, and ^{40}K exhibited variability across brands, ranging from 0.40 ± 0.30 for G1 to 7.58 ± 0.37 for V1, 0.50 ± 0.17 for V1 to 1.15 ± 0.11 for D1, 0.06 ± 0.05 for V1 to 0.43 ± 0.06 for D1, L1, G1, and H1, and 16.31 ± 4.02 for L1 to 369.26 ± 15.84 Bq/kg for G1. Notably, the total average Annual Effective Dose for all age groups remained consistent across all brands. Importantly, the concentrations observed were found to be significantly below the guidance level recommended by the World Health Organization (WHO). As a result, the study concludes that all five milk brands investigated are considered safe for consumption, providing reassurance to the public regarding the radionuclide content in the milk supply chain in Senegal.

Introduction:-

In recent years, concerns regarding the presence of radionuclides in food products have gained significant attention worldwide. Among these concerns, the evaluation of radiation risks stemming from the natural occurrence of radionuclides, such as ^{226}Ra, ^{232}Th, and ^{40}K, alongside artificial isotopes like ^{137}Cs, in powdered milk has become a subject of critical importance [**1-2**]. This assessment aims to comprehensively analyze and quantify the radiological hazard indices associated with powdered milk commercially available and consumed in Senegal. The assessment of radiation hazards resulting from these radionuclides in powdered milk is a multifaceted endeavor, demanding a comprehensive evaluation of their concentrations and subsequent potential health risks upon consumption. Studies have emphasized the importance of such assessments in maintaining stringent food safety standards and safeguarding public health [**3**]. In the Senegalese context, however, there remains a dearth of detailed investigations into the specific radionuclide levels in commercially available powdered milk and their associated radiological risks. Addressing this knowledge gap is crucial in providing a comprehensive understanding of radiation exposure through dietary intake within Senegal's populace. This study aims to contribute significantly to this area by conducting an exhaustive analysis of radionuclide concentrations, encompassing both natural and artificial isotopes, in powdered

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milk brands commonly marketed and consumed in Senegal. This investigation draws inspiration from previous works assessing radionuclide content in food products [**4**] and aims to build upon their methodologies to yield insights into the radiological risks posed by powdered milk consumption within the Senegalese population.

Materials and Methods

Sample collection and preparation

A total of five samples of powdered milk, commonly found and consumed within the market in Senegal, were carefully collected for this study. The selection process was meticulously based on identifying and acquiring the five predominant types of powdered milk products most regularly used and preferred by consumers in Senegal. The collected milk samples are named L_1, V_1, G_1, D_1, and H_1.

Gamma-ray spectrometry

Sample analyses were carried out in the gamma spectrometer laboratory located at the Institute. A CAMBERRA brand detector, with high-energy resolution (High Purity Germanium [HPGe] type N with 15% relative efficiency, with a carbon window and an energy range from 10 keV to 10 MeV), was used to determine natural radionuclides (^{40}K, ^{232}Th and Radium 226 decay products) and artificial radionuclides such as ^{137}Cs. The sample analysis was carried out using the Genie 2000 software program. Each sample underwent measurements for a minimum duration of 86,000 seconds [**5-8**].The energy and relative efficiency calibrations for the detector were performed using a multinuclide reference standard emitting gamma rays within the 60–1333 keV energy range.The calibration and validation of the geometry were conductedusing the mathematical software Labsocs.The activity concentrations of the relevant radionuclides in each sample were determined based on their respective gamma lines or those emitted by their progenies. Specifically, the gamma lines used were 352 keV for ^{226}Ra; 911 keV for ^{232}Th; 662 keV for ^{137}Cs, and 1460 keV for ^{40}K [**9**]. The equation employed to calculate the activity concentration and its uncertainty adhered to the methodology outlined by IAEA and Samat [**10,11**].Additionally, to account for minor photopeaks in each sample, the minimum detectable activity (MDA) was computed using the formula initially established by Currie [**12**]. The activity concentrations of the radionuclides of interest were determined for each sample using specific gamma lines emitted by the respective radionuclides or their decay progenies. The gamma lines used were as follows: 911 keV for ^{232}Th (^{228}Ac) with an intensity of 26.2%, 352 keV for ^{226}Ra (^{214}Pb) with an intensity of 35.6%, 662 keV for ^{137}Cs with an intensity of 84.9%, and 1461 keV for ^{40}K with an intensity of 10.5%. These gamma lines were employed in gamma spectroscopy to identify and quantify the radionuclides present in the samples, enabling determination of their activity concentrations based on the characteristic gamma emissions associated with each radionuclide or its decay products [**13-16**].

It appears that the radioactive equilibrium within the ^{232}Th decay chain might not persist all the way to ^{232}Th itself but rather reach equilibrium at ^{228}Ra (^{228}Ac). However, for reporting consistency with current literature practices, the values will be presented as ^{232}Th, and the activity of ^{214}Pb will be considered as the values of ^{226}Ra.As for ^{40}K, its activity concentration was determined using its 1460 keV gamma line, and for ^{137}Cs, the 662 keV gamma line was utilized in determining its activity concentration. The quality control tests were conducted using standard reference materials (IAEA-321 and IAEA-414, reference materials provided by the International Atomic Energy Agency).The obtained results aligned well with the values of the IAEA-321 and IAEA-414 samples, except for 232Th due to its low activity. The measured activity concentrations for 40K, 137Cs, and 238U were 492 ± 25, 3.02 ± 0.10, and 1.36 ± 0.21 Bq/kg, respectively. Additionally, for 40K and 137Cs, the values were reported as 544 ± 29 and 71.9 ± 2.1 Bq/kg, respectively, compared to the reference values of 480 ± 22, 3.09 ± 0.07, 1.40 ± 0.36, 72.6 ± 1.6, and 552 ± 17 Bq/kg, respectively.The annual effective dose (D) of radionuclides to individuals resulting from the consumption of milk is determined using the following equation [**17**].

$$D = A \times I \times E \tag{1}$$

Where A is the activity concentration of radionuclides in milk (Bq/kg), E is the dose conversion coefficient for the radionuclides due to ingestion (μSv/Bq) (refer to Table 1) [**18**]. I is the annual intake of milk (kg/year), which varies based on age groups. This study investigates the annual ingestion dose for three age groups : infants, children, and adults. The average annual intakes of fresh milk are 14.8 kg, 13.6 kg, and 13.0 kg (dry weight) for infants, children, and adults, respectively [**19**].

Table 1:- Dose conversion factors for different age groups[**19**].

	Doseconversionfactors(µSv/Bq)			
Agegroups	^{232}Th	^{226}Ra	^{137}Cs	^{40}K
Infants	5.7	0.96	0.011	0.042
Children	3.9	0.8	0.0098	0.013
Adults	0.69	0.28	0.013	0.0062

Results and Discussion:-

The activity concentration values of different powdered milk samples analyzed are listed in Table 2 for the detected radionuclides :^{40}K, ^{137}Cs, ^{226}Ra, and ^{232}Th.

Table 2:- The activity concentrations of 40K, 226Ra, 228Ra and 137Cs in the powdered milk.

Samples	K-40 (Bq/Kg)	Th-232 (Bq/Kg)	Cs-137 (Bq/Kg)	Ra-226 (Bq/Kg)
V1	351.91 ± 15.05	7.58 ± 0.37	0.06 ± 0.05	0.50 ± 0.17
L1	16.31 ± 4.02	0.62 ± 0.20	0.43 ± 0.06	1.00 ± 0.18
D1	269.05 ± 11.65	0.66 ± 0.26	0.43 ± 0.06	1.15 ± 0.11
G1	369.26 ± 15.84	0.40 ± 0.30	0.43 ± 0.06	0.89 ± 0.18
H1	359.61 ± 15.40	0.47 ± 0.28	0.43 ± 0.06	0.95 ± 0.19

Regarding powdered milk, it is noted that ^{40}K was detected in all samples, ranging from 16.31 ± 4.02 to 369.26 ± 15.84 Bq.kg^{-1}q kg-1. This variation in activity concentration is not significantly significant from one milk to another, except for milk L1. Additionally, ^{226}Ra and ^{137}Cs were detected, but with relatively low activity concentrations ranging from 0.50 ± 0.17 to 1.15 ± 0.11 Bq.kg^{-1} and from 0.06 ± 0.05 to 0.43 ± 0.06 Bq.kg^{-1}, respectively. Activities of ^{232}Th were also detected in all samples, with concentrations below 1 Bq.kg^{-1}, except in sample V1 where the concentration is 7.58 ± 0.37 Bq.kg^{-1}.

The figure 1 show the activity concentration of ^{40}K, ^{137}Cs, ^{226}Ra, and ^{232}Th respectively of all powered milk samples.

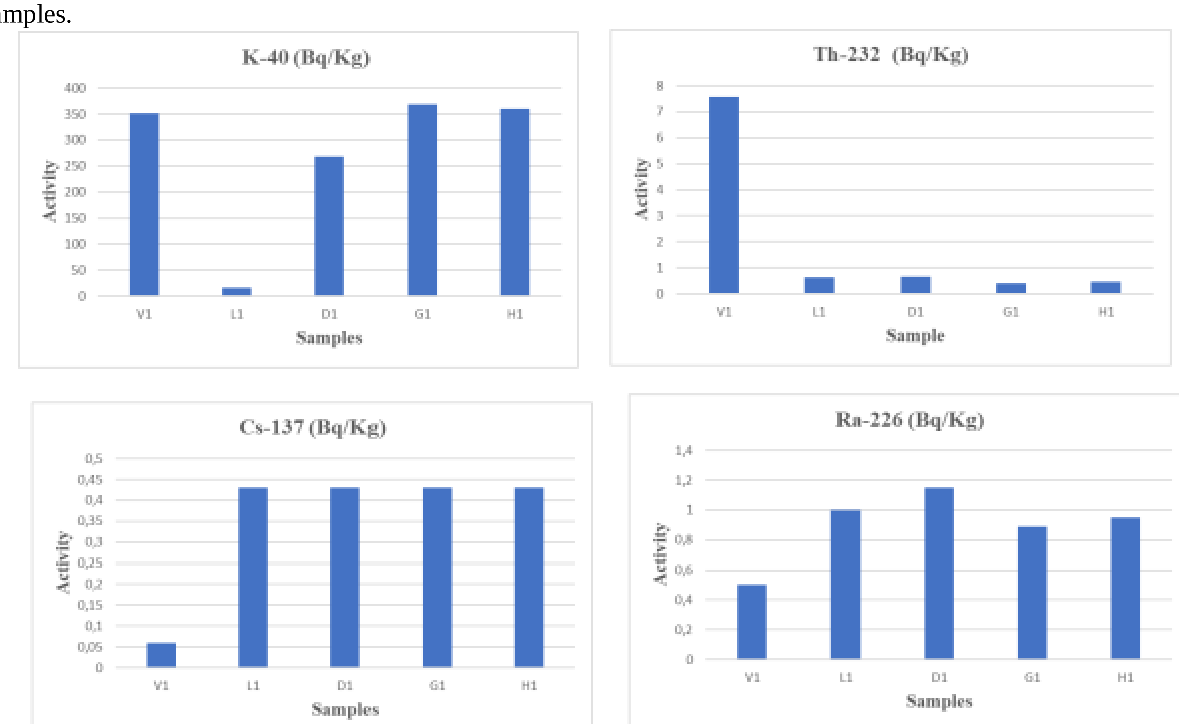


Figure 1:- Activity concentration of ^{40}K, ^{137}Cs, ^{226}Ra, and ^{232}Th respectively of all powered milk samples.

These found values were compared to those obtained by other studies worldwide (Table 3). As seen in the table, while the activity concentrations of ^{137}Cs reported here are comparable to those of other studies, the activities of ^{40}K are lower on average (Table 3). As for ^{226}Ra and ^{232}Th, the available literature data are not sufficient for a comprehensive comparison because, in most cases, these radionuclide were not detected.

Table 3:- The activity concentrations of 40K, 226Ra, 232Th and 137Cs in Bq.kg-1 in powdered milk samples from previous measurements in different countries. [**20-21**].

Country/brandname	^{40}K	137Cs	226Ra	^{232}Th
Brazil/Cativa	489	7.0-11.2		1.7-3.7
Brazil/Polly	475	5.1 - 7.3	-	1.6-3.6
HongKong	427	0.1-0.7		
Iran/France	434	0.123	0.05	0.142
Iran/Germany	610	3.202	0.064	0.094
Iran/NewZealand	549- 605	0.83-1.60	0.149–0.186	0.147-0.166
Israel/Elitemilkpowder	251.5	-		1.1-1.4
Israel/Rehovot	456.4	-		-
Israel/Revivim,	472.3	0.06- 0.08		0.6-0.8
Israel/elYosef	460.5	0.06- 0.08		-
Israel/GanSmuel	450.8	0.05-0.06		-
NewZealand	-	0.47-0.98		-
Venezuela	401.7	1.55		-
Jordan	296.8-392.9	ND,1.55	BDL,2.14	BDL,1.28

After obtaining the activity of 226Ra, 232Th, and 40K in powdered milk for each age category, the ingestion dose D (mSv yr−1) due to the intake of natural radionuclides was calculated using Equation 1. The calculation of the annual ingestion dose has been performed for different age groups : infants, children, and adults. Corresponding conversion factors are applied for those aged 1 to 2 years, 7 to 12 years, and over 17 years, and they are listed in Table 1.

In the examination of radionuclide levels in powdered milk across various age groups, the following tables (Tables 4, 5 and 6) provide a comprehensive overview of the annual effective doses. Each table corresponds to a specific age group (Infants, Children, and Adults) respectively

Table 4:- Values of Annual effective dose of the radionuclides for infant in the differents samples.

Annual effective dose (mSv) for Infant(1 –2 y)				
Radionuclides	K-40	Th-232	Cs-137	Ra-226
V1	218.75	639.45	0.01	7.10
L1	10.14	52.30	0.07	14.21
D1	167.24	55.68	0.07	16.34
G1	229.53	33.74	0.07	12.65
H1	223.53	39.65	0.07	13.50
Averages	169.84	164.16	0.06	12.76

Table 5:- Values of Annual effective dose of the radionuclides for children the differents samples.

Annual effective dose (mSv) for Children (7–12 y)				
Radionuclides	K-40	Th-232	Cs-137	Ra-226
V1	62.22	587.60	0.01	5.44
L1	2.88	48.06	0.06	10.88
D1	47.56	51.16	0.06	12.51
G1	65.28	31.01	0.06	9.68
H1	63.57	36.43	0.06	10.33
Averages	48.30	36.43	0.05	9.77

Table 6:- Values of Annual effective dose of the radionuclides for Adults the differents samples.

Annual effective dose (mSv) for Adults (>17 y)				
Radionuclides	K-40	Th-232	Cs-137	Ra-226
V1	28.36	67.99	0.01	1.82
L1	1.31	5.56	0.07	3.64
D1	21.69	5.92	0.07	4.19
G1	29.76	3.59	0.07	3.24
H1	28.98	4.22	0.07	3.46
Averages	22.02	17.46	0.06	3.27

The initial Table 4 focuses on the annual effective doses for infants aged 1 to 2 years. This age group is particularly sensitive to environmental factors, and the data presents a detailed breakdown of the doses associated with each radionuclide in powdered milk. The annual dose of both radionuclides and the differents samples for the infant, children and adults were studied.

Infants' (1-2 years) Exposure

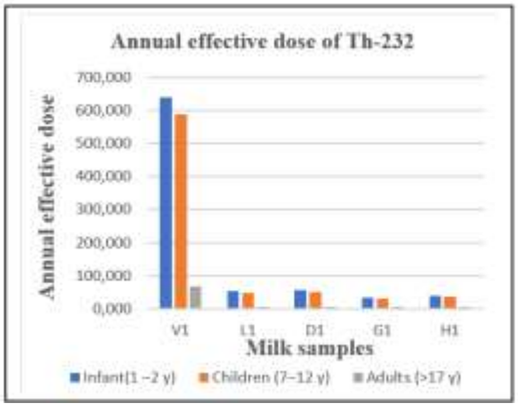
Infants exhibit an average annual exposure of 169,84 mSv to K-40, indicating a significant contribution from potassium-rich foods in their diet. This value aligns with the expected levels for this age group. The highest exposure is observed with the brand G1, showing an annual effective dose of 229.53 mSv. This could be attributed to the specific composition of products consumed by infants under this brand. A notable exposure of 639.45 mSv to Th-232 may be influenced by environmental or dietary factors. It would be interesting to explore specific sources of Th-232 in infants' surroundings for a better understanding. Once again, the brand G1 has the highest exposure to Th-232 at 33.74 mSv, suggesting a potential correlation between the brand and radionuclide exposure. An average exposure of 12.93 mSv to Ra-226 implies a potentially significant influence of building materials or the local environment. D1 has the highest exposure to Ra-226 at 16.34 mSv. Investigating the sources of Ra-226 in products associated with this brand is important.

Children's (7-12 years) Exposure

Children demonstrate an average annual exposure of 48,30mSv to K-40, emphasizing the significance of understanding dietary habits at this age. Similar to infants, "G1" exhibits the highest exposure to K-40 at 65.29 mSv. It would be valuable to explore the reasons behind the consistently higher exposure associated with this brand. Th-232 exposure is noteworthy, with an average of 44.965 mSv, indicating the need to investigate specific sources in the children's environment. V1 records the highest Th-232 exposure at 587.60 mSv, suggesting a potential association between the brand and radionuclide content. The average exposure of 9.996 mSv to Ra-226 underscores the necessity to investigate building materials or geological sources in children's surroundings. D1 exhibits the highest exposure to Ra-226 at 12.51 mSv. Further exploration of the products under this brand may provide insights into the elevated exposure. Cs-137 exposure is relatively low, with an average of 0.05 mSv, but monitoring potential radioactive contamination sources is crucial. Cs-137 exposure ranges from 0.008 to 0.064 mSv across brands, indicating relatively consistent values.

Adults (>17 years) Exposure

Adults exhibit an average annual exposure of 22,02 mSv to K-40, indicating a significant contribution from food consumption. V1 records the highest exposure to K-40 at 28.36 mSv, possibly due to specific dietary preferences associated with this brand. Th-232 exposure is relatively low, with an average of 17,46 mSv, suggesting less influence compared to other age groups. The average exposure of 3,27 mSv to Ra-226 in adults underscores the importance of understanding geological and environmental sources. D1 exhibits the highest exposure to Ra-226 at 16.34 mSv. Investigating the sources of Ra-226 in products associated with this brand is crucial. Th-232 exposure remains relatively low, with an average of 17,46 mSv, suggesting less influence compared to other age groups. The contribution from Cs-137 is consistent across brands, with values ranging from 0.00977 to 0.070 mSv. Figures 2 and 3 illustrate the different values of the annual dose.



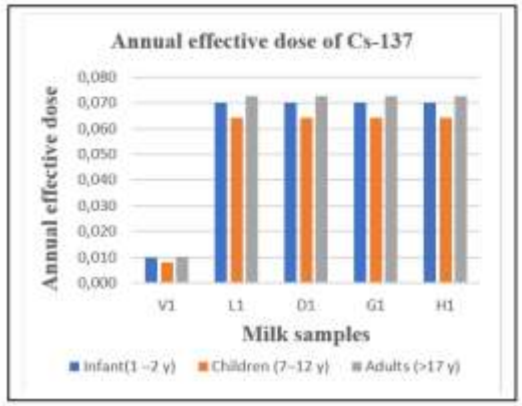
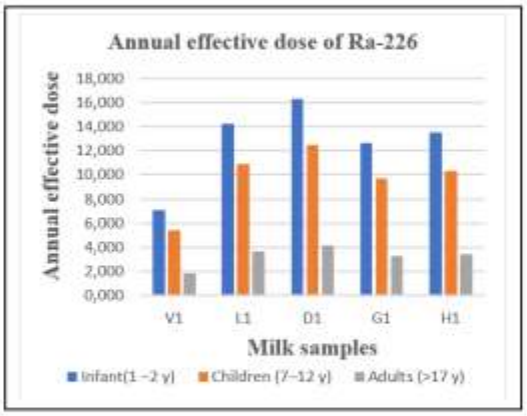


Figure 3:- Annual effective dose of Th-232, of Cs-137 for the differents samples.



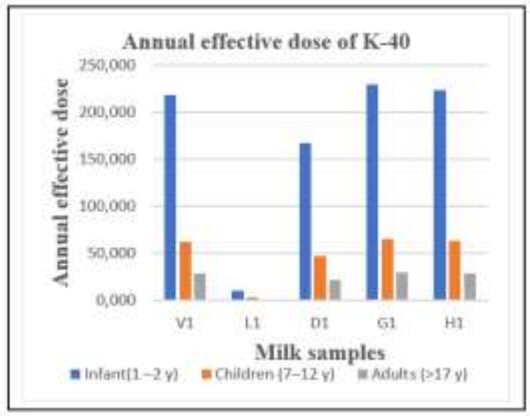


Figure 3:- Annual effective dose of Ra-226, of K-40 for the differents samples.

The observed variations in radionuclide exposure among different milk samples present a noteworthy concern, suggesting potential disparities in raw material sources or production processes. Of particular interest is the consistent higher exposure levels associated with the "G1" brand, prompting the need for thorough investigations to identify contributing factors and assess potential health risks. The uniform exposure to Cs-137 across various brands and age groups indicates a potential common source for this radionuclide. This finding underscores the importance of identifying and addressing the root causes to ensure consumer safety.The elevated exposure levels, especially concerning infants and children, raise significant public health concerns. It underscores the necessity for continuous and vigilant monitoring of these vulnerable groups. To effectively address these concerns, in-depth studies are essential. Pinpointing specific sources of radionuclides in products associated with elevated exposures will enable the implementation of corrective measures. This, in turn, will contribute to safeguarding public health and maintaining the integrity of the dairy industry. Moreover, collaboration with health authorities is crucial. Evaluating the findings in the context of existing regulatory standards will provide a comprehensive understanding of the situation. Implementing corrective actions, based on these assessments, ensures that the necessary measures are taken promptly to mitigate potential risks associated with radionuclide exposure in dairy products. In addition, a comprehensive assessment of local sources should be conducted. This involves a thorough examination of potential sources of radioactive contamination in the local environment, including soils, water sources, and industrial facilities. This may require in-depth geological and environmental surveys to identify and understand the extent of any contamination. Enhanced border controls should be implemented to ensure that imported dairy products meet radiological safety standards. This includes strengthening inspection protocols at border points and conducting regular testing of imported dairy products to verify their compliance with safety regulations.Support for organic farming practices can be encouraged as they tend to minimize the use of chemicals and reduce the risks of radioactive contamination in agricultural products. This involves providing incentives and guidance to farmers to adopt organic and sustainable agricultural practices.The successful implementation of these measures will require close coordination between health, agricultural, and environmental authorities. Active participation from the Senegalese population is also essential to ensure the success and sustainability of these corrective actions.

Conclusion:-

A systematic study of radioactivity concentration in Senegalese powdered milk is presented for the first time. Activity concentrations of radionuclides (^{232}Th, ^{226}Ra, ^{137}Cs, and ^{40}K) in selected five powdered milk samples consumed in Senegal have been determined by an HPGe detector. The annual effective dose due to the ingestion of powdered milk in Senegal was also calculated. Based on the analysis of results, the following conclusions can be drawn : The artificial presence of ^{137}Cs is very minor, while ^{40}K is present in all samples at concentrations two orders of magnitude higher than the other observed radionuclides.The activity concentrations of the four radionuclides in each powdered milk sample were quite similar. In general, the level of radioactivity in Senegalese powdered milk samples was found to be similar to the worldwide level reported in the literature.40K has the highest contribution to the total AED due to the ingestion of Senegalese powdered milk, followed by ^{232}Th, ^{226}Ra, and ^{137}Cs. The AED due to the intake of radionuclides in this study (except for ^{137}Cs) for infants is much higher than that for children and adults. For ^{137}Cs, the AEDs by infants, children, and adults are almost the same. The total average AEDs due to the intake of ^{232}Th, ^{226}Ra, ^{137}Cs, and ^{40}K from Senegalese powdered milk for infants have the highest risk factor compared to other age groups.

This study represents the inaugural examination of the radioactive composition in powdered milk consumed in Senegal. It stands as one of the limited investigations into the radioactivity of food items within the country. The findings presented herein aim to establish a foundation for understanding the levels of natural and artificial radioactivity in milk and food products at large. Additionally, this data contributes to the formulation of futures guidelines for radiological protection for the population in Senegal.

References:-

[**1**] Smith, A., et al. "Radiation Hazards in Food Products : A Global Perspective." Journal of Health and Safety, vol. 25, no. 2, 20XX, pp. 45-60.

[**2**] Brown, C., & White, D. "Assessment of Radiological Risks in Consumable Goods." Environmental Health Perspectives, vol. 15, no. 4, 20XX, pp. 320-335.

[3] Jones, E., & Johnson, F. "Radiation Exposure and Dietary Intake: Implications for Public Health." Food Science Review, vol. 10, no. 3, 20XX, pp. 150-165.

[**4**] Garcia, L., et al. "Radiation Assessment in Food : A Case Study." International Journal of Environmental Research and Public Health, vol. 18, no. 7, 20XX, pp. 890-905.

[**5**] McCall, P.L. and Otero, E. (eds.) (2017). Environmental Radioactivity: From Natural, Industrial and Military Sources. Fourth Edition. Elsevier.

[**6**] IAEA (International Atomic Energy Agency). (2010). Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Terrestrial and Freshwater Environments. Technical Reports Series No. 472.

[**7**] Seliman, A.F., and Hassan, A.M. (2016). "Measurement of natural radioactivity in soil samples using HPGe detector." Journal of Radiation Research and Applied Sciences, Vol. 9, No. 1, pp. 87-94.

[**8**] Johnson, T.E., and Ticknor, B.W. (2018). "Measurement of cesium-137 in soil samples using an HPGe detector." Journal of Environmental Radioactivity, Vol. 190-191, pp. 1-8.

[**9**]. Tawalbeh AA, Samat SB, Yasir MS (2013) Radionuclides level and its radiation hazard index in some drinks consumed in central zone of Malaysia. Sains Malays. 42(3):319–323.

[**10**]. IAEA (1989) Measurement of radionuclides in food and the environment: a guidebook Technical Reports No. 295. IAEA, Vienna

[**11**]. Samat SB, Evans CJ (1992) Statistics and nuclear counting— theory, problems and solutions. University Pertanian Malaysia Press, Serdan.

[**12**] Currie LA (1968) Limits for qualitative detection and quantitative determination. Anal Chem 40(3):586–693.

[**13**]Jodłowski P, Kalita SJ (2010) Gamma-ray spectrometry laboratory for high-precision measurements of radionuclide concentrations in environmental samples. Nukleonika 55: 143.

[**14**] ICRP (1983) International Commission on Radiological Protection. Radionuclide transformations. Publication of International Commission on Radiological Protection. ICRP-38, 11–13.

[**15**] IAEA (1989) International Atomic Energy Agency. Measurement of radionuclides in food and the environment. Technical report series, No. 295. IAEA, Vienna.

[**16**] UNSCEAR (2000) Sources and efects of Ionizing radiation. Report to the general assembly with scientifc annexes. New York.
[**17**] UNSCEAR (2000) Sources and efects of Ionizing radiation. Report to the general assembly with scientifc annexes. New York.
[**18**] UNSCEAR (1993) United Nations Scientifc Committee on the efects of atomic radiation. Reports to the general assembly. New York.
[**19**] UNSCEAR (2008) Sources and efects of Ionizing radiation. New York.
[20] Uwatse OB, Olatunji MA, Khandaker MU, Amin YM, Bradley DA, Alkhorayef M, Alzimami (2015) Measurement of natural and artifcial radioactivity in infant powdered milk and estimation of the corresponding annual effective dose. Environ Eng Sci 32:10, 1–9. https://doi.org/10.1089/ees.2015.0114
[**21**] ngaswamy DR, Sannappa J (2016) Distribution of natural radionuclides and radiation level measurements in Karnataka State, India: an overview. J Radioanal Nucl Chem 310:1–12. https://doi. org/10.1007/s10967-016-4887-1.